APPENDIX A
NOTIFIED Ka BAND SPACE STATIONS

TABLE 1

Ka Band (17.3-31 GHz) GSO Satellites on the latest ITU Space Network List

Country of Status	Status			
Administration	**A**	**C**	**N**	**Grand Total**
Australia	0	1	1	2
Belgium	0	1	0	1
Canada	1	0	0	1
Germany	1	2	2	5
France	11	1	1	13
ESA	6	0	1	7
United Kingdom	11	0	1	12
Italy	3	3	1	7
Japan	0	7	8	15
Russia	5	0	2	7
NOTELSAT	0	0	1	1
"USSR"	1	23	4	28
United States	11	28	11	50
Grand Total	**50**	**66**	**33**	**149**

TABLE 2

Notified Ka-Band Space Stations from ITU Space Network List

Longitude	Administration	Space Station
156.00E	Australia	AUSSAT B 156E S
23.50E	Germany	DFS-1
28.50E	Germany	DFS-2
19.00W	France	TDF-1
19.00W	ESA	L-SAT
31.00W	United Kingdom	BSB-1
13.00E	Italy	ITALSAT
132.00E	Japan	CS-2A
132.00E	Japan	CS-3A
135.00E	Japan	CSE
136.00E	Japan	CS-2B
136.00E	Japan	CS-3B
154.00E	Japan	ETS-6-FSM
154.00E	Japan	ETS-6-ISM
162.00E	Japan	SUPERBIRD-B
76.00E	Russia	GOMS-M
166.00E	Russia	GOMS-2M
5.00E	NOTELSAT	TELE-X
170.00W	"USSR"	TOR-5
14.50W	"USSR"	GOMS-1M
45.00E	"USSR"	TOR-3
85.00E	"USSR"	TOR-4
174.00W	United States	ATDRS 174W
171.00W	United States	ATDRS 171W
145.00W	United States	FLTSATCOM-C W PAC3
105.00W	United States	FLTSATCOM-C E PAC1
100.00W	United States	ACTS
100.00W	United States	FLTSATCOM-B EAST PA
100.00W	United States	FLTSATCOM-C E PAC2
46.00W	United States	ATDRS 46W
41.00W	United States	ATDRS 41W
22.50W	United States	FLTSATCOM-B EAST AT
172.00E	United States	FLTSATCOM-C W PAC1

APPENDIX B

Date: April 12, 1995
Original: English

Co-Directional Frequency Sharing Between MSS Feeder Links of NGSO-MEO System and NGSO Satellite Systems (FSS and MSS, Service and Feeder Links) in the 30/20 GHz Band

1.0 Introduction:

Informal Working Group 4 (IWG-4) of the FCC Industry Advisory Committee for WRC-95 is tasked with developing an U.S. industry consensus position on proposals for preferred FSS frequency bands which could support MSS feeder link spectrum. As such, this paper presents extensive analysis and simulation results related to the feasibility of co-directional frequency sharing between NGSO-MEO MSS feeder links, and FSS and MSS service links and feeder links of other NGSO Satellite Systems. The feasibility of co-directional frequency sharing between the feeder links of an NGSO-MEO system and NGSO Satellite Systems is necessary in determining the optimum choice of frequency bands for these services.

The LEO B system is used as an example of an NGSO-MEO MSS system with feeder links operating in Ka-Band. The LEOSAT-1 system is used as a representative example of an NGSO satellite service operating in Ka-Band. It has both FSS and MSS service links, and MSS feeder-links. Extensive computer simulation runs are used to calculate the statistics of the interference between the links of the two systems. The two representative systems have proposed to operate at different Ka-band frequencies and thus the analysis presented in this paper only examines the possibility of co-frequency sharing.

2. Technical Characteristics of the Satellite Systems

Table 2.1 shows the orbital parameters of the two systems. The Technical characteristics of the communication systems of both systems are shown in Table 2.2. The antenna patterns are shown in Figures 2.2 to 2.11. The NGSO Satellite Service network uses a constellation of 840 operational interlinked low-Earth orbit (LEO) satellites. The Earth's surface is mapped into a fixed grid of

approximately 20,000 supercells. Each supercell is a square with sides of 160 km in length. Each supercell is further divided into 9 square cells of area 53.3 km × 53.3 km each. The network uses a combination of space, time, and frequency division multiple access techniques. At any instant in time, each fixed supercell is served by 1 of the 64 transmit and 1 of the 64 receive beams on one of the satellites. The scanning beam scans the 9 cells within the supercell with a 23.111 msec scan cycle, resulting in time division multiple access among the cells in a supercells. Physical separation and a checkerboard pattern of left and right circular polarization eliminate interference among cells scanned at the same time in adjacent supercells. Within each cell's time slot, terminals use Frequency Division Multiple Access (FDMA) on the uplink and Asynchronous Time Division Multiple Access (ATDMA) on the downlink.

Orbital Parameters	**NGSO Satellite System**	**MEO-Based MSS Feeder-Link**
No. of Planes	21	3
No. of Satellites Per Plane	44	4
Altitude	700 km	10355
Inclination	98.2°	50.0°

Table 2.1 Orbital Parameters

	NGSO Satellite System			**MEO-Based MSS**
	Standard Links	Mobile Links	High Rate Links	Feeder-Links
Uplink Polarization	LHC/RHC	LHC/RHC	LHC/RHC	LHC
Downlink Polarization	LHC/RHC	LHC/RHC	LHC/RHC	RHC
Satellite Transmit Power (dBW)	18.8	18.8	-5.5 to 6.6	1.3 /carrier
Earth Station Transmit Power (dBW)	-20.3 to -1.9	-20.3 to -1.9	-3.8 to 16.9	-2.3 to 3.0 per carrier
Satellite Receive Bandwidth (MHz)	0.275	0.275	800	2.5 /carrier
Earth Station Receive Bandwidth (MHz)	396	99	800	2.5 /carrier
Required C/I Protection Ratio (dB)	25	25	25	18.2

Table 2.2 Communications Parameters

The NGSO Satellite Service network uses a wide variety of earth stations to support different kind of services and users. The Standard Earth Stations and the High Rate Earth Stations support FSS service and Feeder Links. The Mobile Earth Stations support MSS applications with the Standard Earth Stations and the High Rate Earth Stations providing the required feeder links. The three types

of Earth stations are described below. Figure 2.1 depicts the data flow between them.

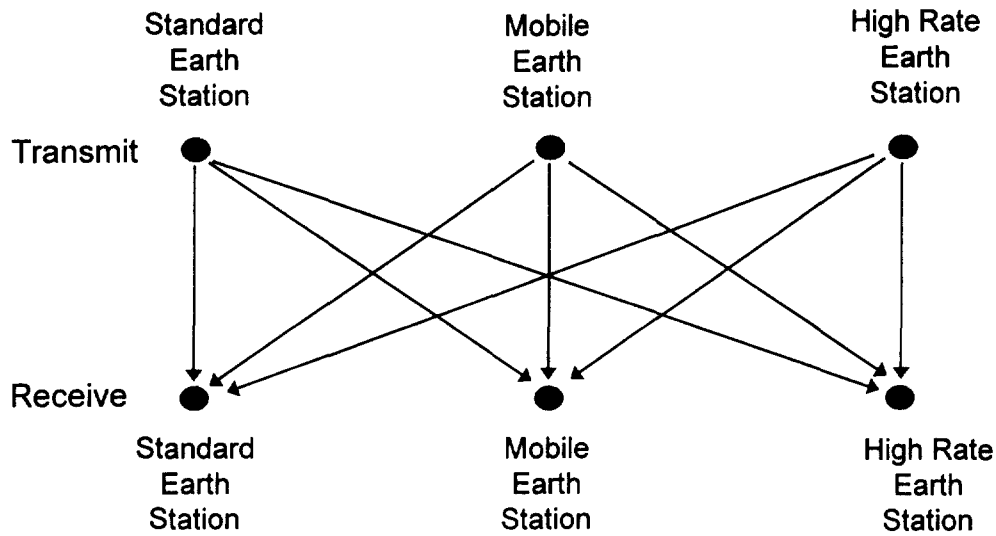

Figure 2.1 NGSO Satellite Service Network Data Flow

a. Standard Earth Stations

The Standard Earth Stations are designed to accommodate data rates from 16 kbps (Basic Channel) up to 2.048 Mbps (E1). Hundreds of these earth stations can be located within a single cell, but at any instant of time, only up to 1440 basic channel earth stations or 15 T1 rate (1.544 Mbps) earth stations or a combination of different data rate earth stations are allowed to operate simultaneously within a single cell.

Each cell within a supercell will be scanned by the satellite in a time division multiplexed manner, so the transmission is bursty with a duty cycle of about 10%. For uplinks within a cell, signals from different terminals are frequency multiplexed within the 400 MHz bandwidth available. The frequency band assigned to a certain terminal depends on the data rate the terminal requested. The downlinks operates in ATDMA manner. The satellite transmits a series of packets addressed to terminals within a cell. A terminal only selects those packets that are addressed to it. Figures 2.8 and 2.9 show the antenna patterns of the Standard Earth Station and Figure 2.6 shows the contour of the satellite antenna footprint for the Satellite Standard Link.

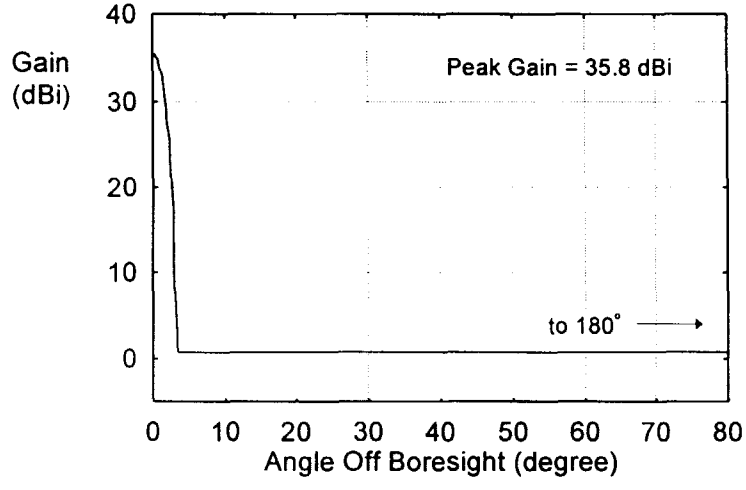

Figure 2.2 NGSO-MEO MSS Feeder-Link Satellite Transmit Antenna Pattern

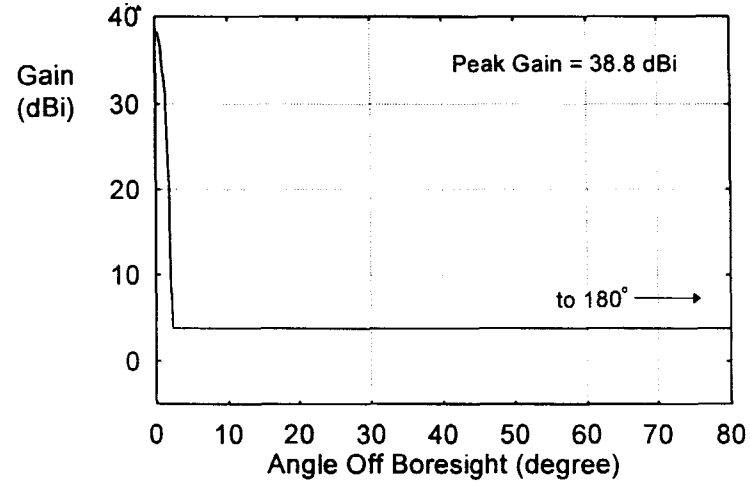

Figure 2.3 NGSO-MEO MSS Feeder-Link Satellite Receive Antenna Pattern

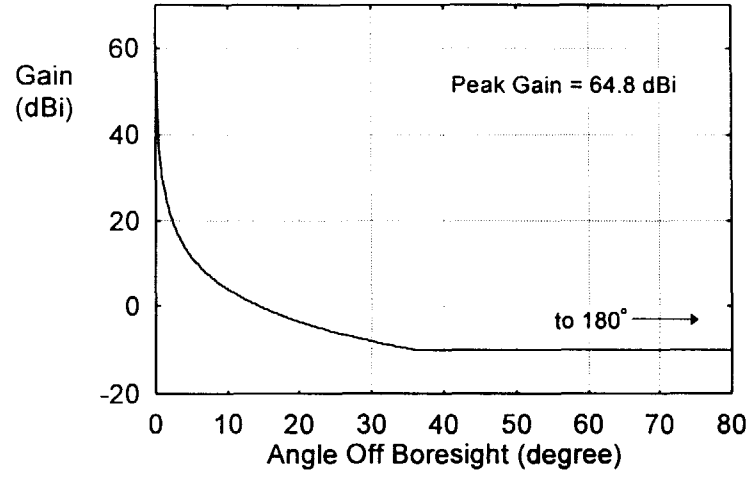

Figure 2.4 NGSO-MEO MSS Feeder-Link Earth Station Transmit Antenna Pattern

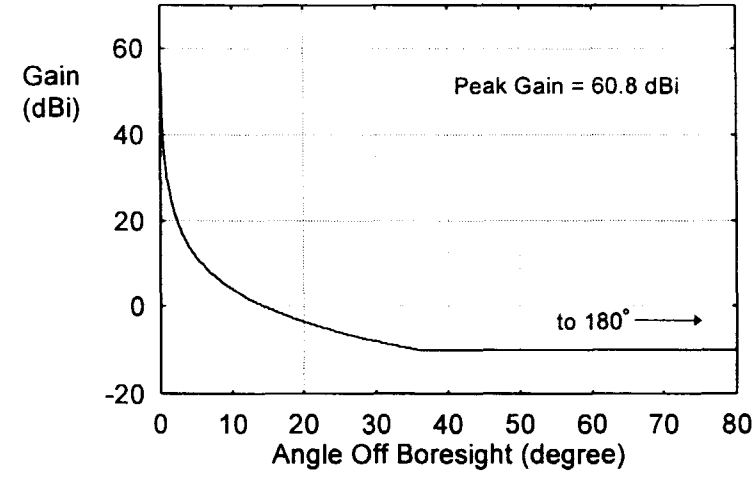

Figure 2.5 NGSO-MEO MSS Feeder-Link Earth Station Receive Antenna Pattern

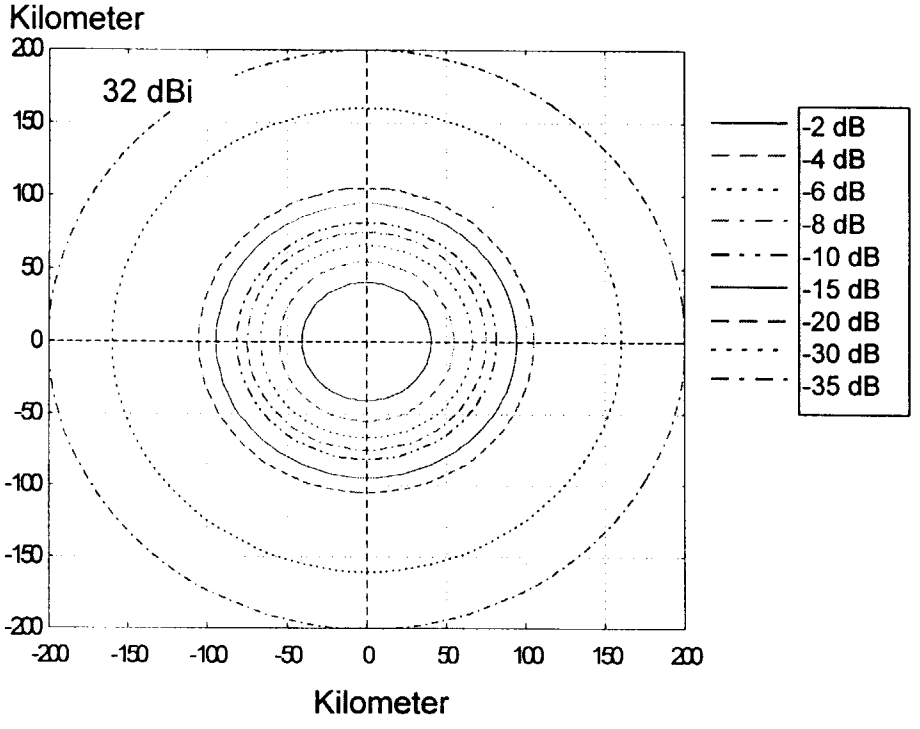

Figure 2.6 NGSO Satellite System Standard Link and Mobile Link Satellite Antenna Transmit and Receive Gain Contours

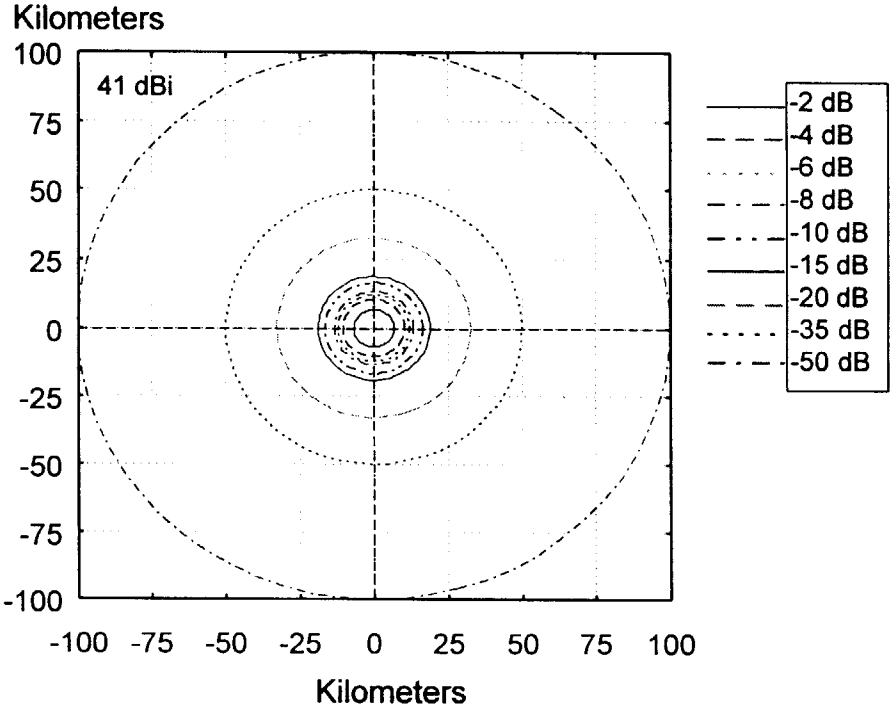

Figure 2.7 NGSO Satellite System High Rate Link Satellite Antenna Transmit and Receive Gain Pattern

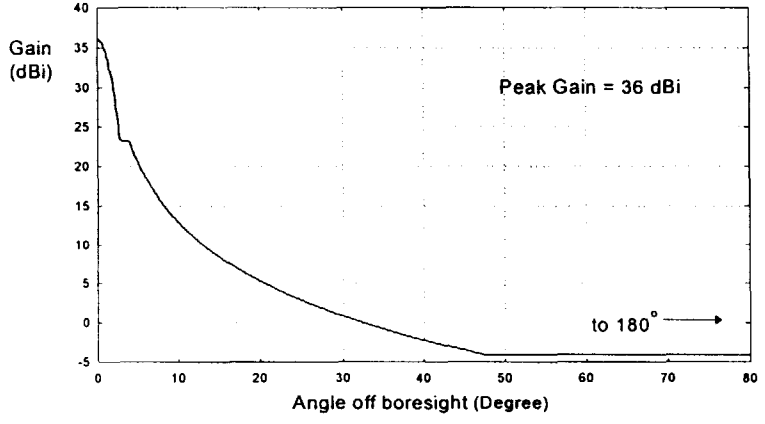

Figure 2.8 NGSO Satellite System Standard Earth Station and Mobile Earth Station Transmit Antenna Pattern

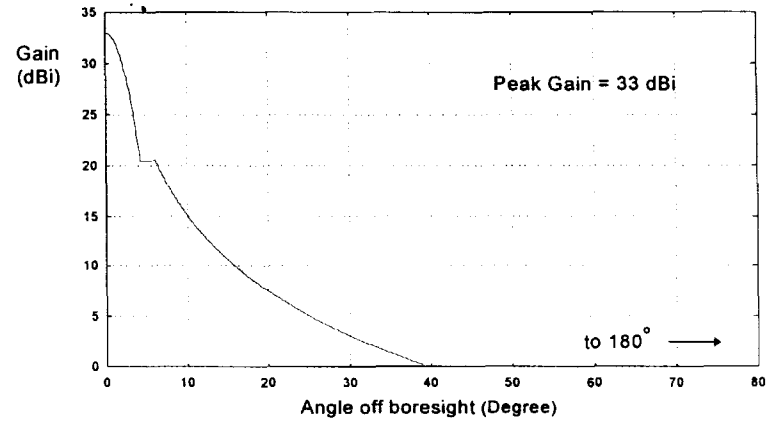

Figure 2.9 NGSO Satellite System Standard Earth Station and Mobile Earth Station Receive Antenna Pattern

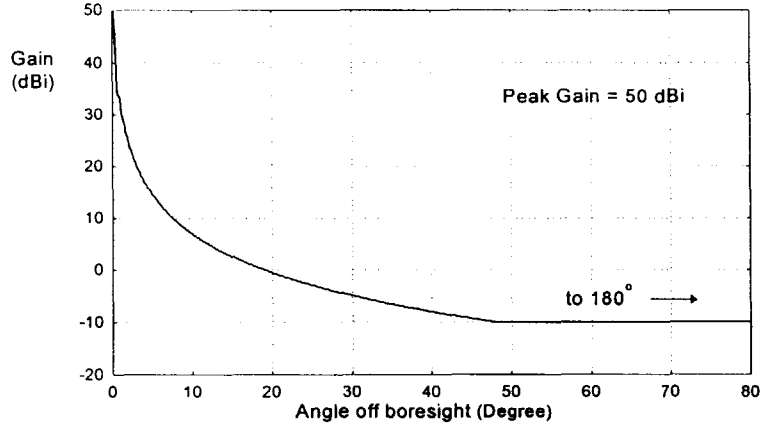

Figure 2.10 NGSO Satellite System High Rate Earth Station Transmit Antenna Pattern

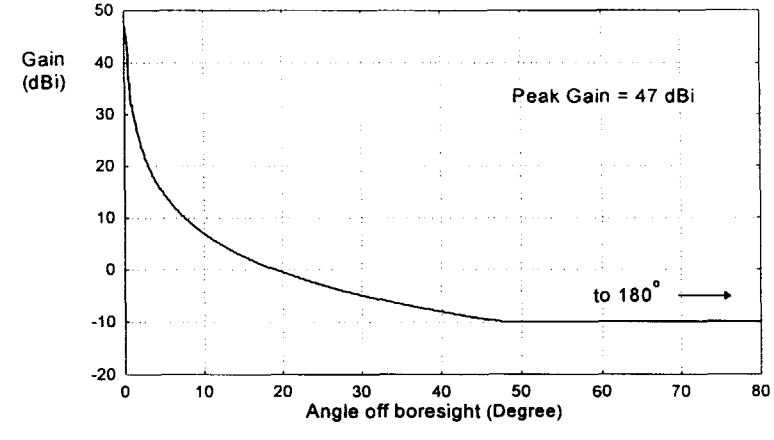

Figure 2.11 NGSO Satellite System High Rate Earth Station Receive Antenna Pattern

b. Mobile Earth Stations

The NGSO Satellite Services network also supports Mobile Earth Stations. The Mobile Earth Stations operate at multiple rates of the 16 kbps up to 2.048 Mbps (E1). The operation of the Mobile Earth Stations are similar to the Standard Earth Stations with following exceptions:
- The Mobile Earth Station can use a smaller antenna.
- The bandwidth for MSS is 100 Mhz which can accommodate up to 360 basic channels in each cell.

The antenna patterns for the Mobile Standard Terminal and the Satellite Mobile Links are the same as the Satellite Standard Links as shown in Figures 2.8, 2.9 and 2.6.

c. High Rate Earth Station

The NGSO Satellite Service network also supports a smaller number of fixed-site High Rate Earth Stations that operate at the OC-3 rate (155.52 Mbps) and multiples of this rate up to OC-24 (1.24416 Gbps). Each satellite can support up to sixteen High Rate Earth Stations within its service area. Figures 2.10 and 2.11 show the antenna patterns of the High Rate Earth Station and Figure 2.7 shows the contour of the satellite antenna footprint for the Satellite High Rate Link.

3.0 Interference Analysis

In order to calculate the complex, time-varying interference statistics between the MSS Feeder Links of the NGSO-MEO system and the NGSO Satellite Service links, a detailed computer simulation program is developed. The simulation program is based on software modules that have been previously developed and tested. The results of the simulation runs were validated by simple analysis and by comparison to another independently developed simplified simulation program.

The simulation program includes the satellite orbital ephemeris and visibility characteristics as viewed from any given location on the earth. It allows for a wide range of choices in specifying the NGSO orbital parameters, link parameters, and simulation duration and step size. The output of the simulation program at each step size is the Carrier to Interference power ratio at the interfered with receiver as given by:

$$C/I = P_T^C + G_T^C(0) - PL^C + G_R^C(0) - 10 \cdot \log \sum_{\text{for all } I} 10^{P_T^I + G_T^I(\theta_{I/C}) - PL^{I/C} + G_R^C(\theta_{C/I}) - BWF^{I/C}}$$

where

P_T^C is the desired signal transmit power (dBW)

$G_T^C(0)$ is desired signal transmit antenna peak gain (dB)

PL^C is the path loss from the desired transmitter to the receiver (dB)

$G_R^C(0)$ is the receiver antenna peak gain (dB)

P_T^I is the interference signal transmit power (dBW)

$G_T^C(\theta_{I/C})$ is the interference signal transmit antenna gain in the direction of the receiver (dB)

$PL^{I/C}$ is the path loss from the interfering transmitter to the receiver (dB)

$G_R^C(\theta_{C/I})$ is the receiver antenna gain in the direction of the interfering transmitter (dB)

$BWF^{I/C}$ is a bandwidth factor equal to 0 dB if the interference signal transmit bandwidth is less than or equal to the desired receive bandwidth and it is equal to $10\ Log_{10}\ (\ BW_{transmit}\ /\ BW_{receive}\ )$ if the interference signal transmit bandwidth is greater than the desired signal receive bandwidth.

There are four possible interference cases. In each of these cases the interference statistics between the MSS feeder links of the NGSO-MEO system and the three link types of the NGSO Satellite Service network are calculated. Figure 3.1 depicts the distribution of the NSGO Satellite Service Standard and Mobile Earth Stations around the MSS Feeder Link Earth Station of the NGSO-MEO system. It is assumed that one earth station is collocated with the NGSO-MEO MSS Feeder Link Earth Station. Furthermore it is assumed that in other cells that are separated by 160 km there are other NGSO Service Satellite Earth Stations communicating with the NGSO satellite. A grid of 21 by 21 or a total of 441 Standard Earth Stations or Mobile Earth Stations are considered. In some of the analysis the collocated earth station is removed in the interference calculations to evaluate the sensitivity of the interference statistics to the minimum distance between an NGSO Standard or Mobile Earth Station and the MSS Feeder Link Earth Station of the NGSO-MEO system. Figure 3.2 depicts the distribution of nine High Rate Earth Stations with one of them collocated with the MSS Feeder Link Earth Station of the NGSO-MEO system.

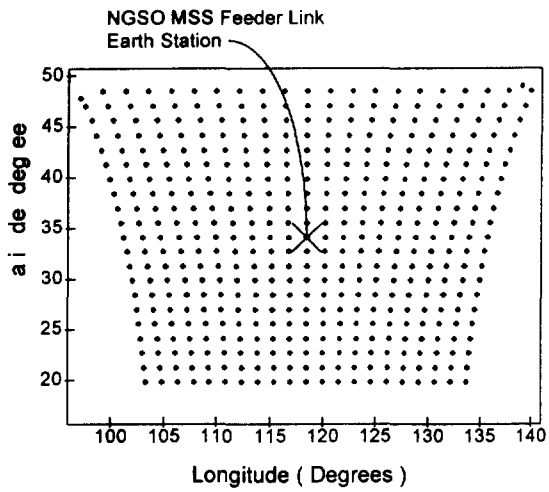

Figure 3.1: Ground Segment Distribution of NGSO Standard Earth Stations

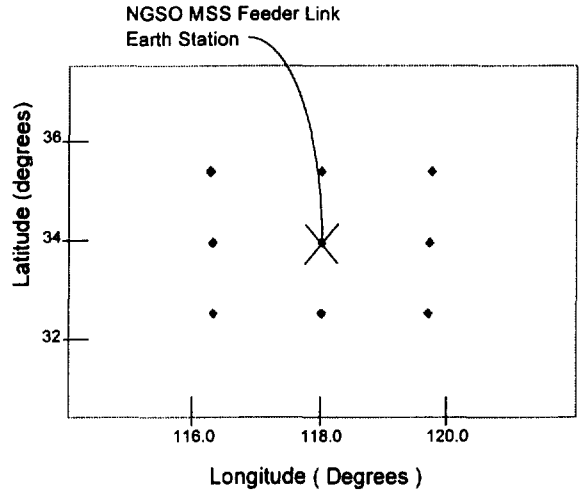

Figure 3.2: Ground Segment Distribution of NGSO High Rate Earth Stations

In what follows each of the interference cases are described and the method used in calculating the interference statistics is outlined.

Case 1 : Interference from an NGSO Satellite into the MSS Feeder Link Earth Station of the NGSO-MEO System

This case is shown in figure 3.3. At each simulation step the carrier power at the MSS Feeder Link Earth Station of the NGSO-MEO system receiver is calculated by locating the closest satellite to the Earth Station with an elevation angle of greater than 10 degrees. The downlink of the NGSO-MEO system does not employ power control procedure to compensate for the range.

The interference power at the MSS Feeder Link Earth Station of the NGSO-MEO system receiver is calculated by summing the interference power received from all the NGSO satellites communicating with their corresponding earth stations. For each NGSO Earth Station the corresponding NSGO satellite that is closest to it which has elevation angle of at least 40° is found and the interference power from that satellite to the MSS Feeder Link Earth Station is calculated. The antenna discrimination from the NGSO satellite antenna is found by calculating the distance between the MSS Feeder Link Earth Station of the NGSO-MEO system and the NGSO Earth Station communicating with the satellite.

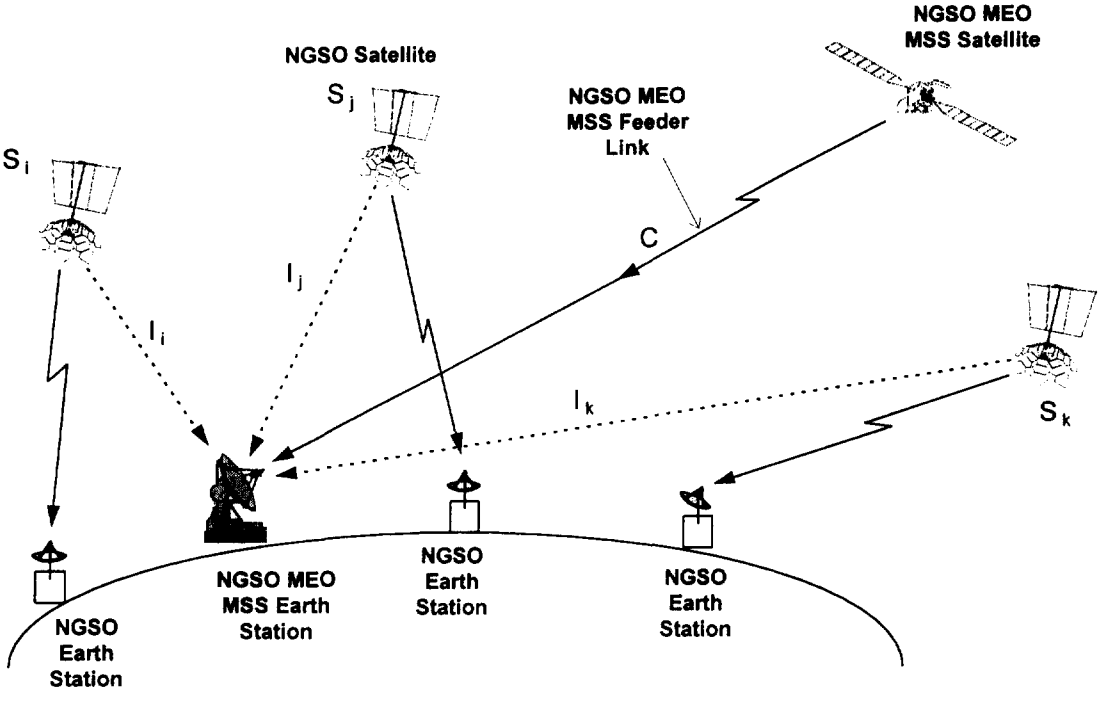

Figure 3.3 Case 1: Interference from NGSO Satellite into the MSS Feeder Link of the NGSO-MEO System

Parameter	Desired	NGSO Interference			Units
	MSS Feeder Link of NGSO-MEO	Standard Link	Mobile Link	High Rate Link	
+ Transmit Power	1.3 / Carrier	18.8	18.8	-5.5	dBW
+ Transmit Antenna Peak Gain	35.8	29.8	29.8	41.0	dBi
= Transmitted EIRP	37.1	48.6	48.6	35.5	dBW
- Transmission Loss	198.3	174.9	174.9	174.9	dB
+ Receiving Antenna Peak Gain	60.8	60.8	60.8	60.8	dBi
= Received Carrier Power	-100.4				dBW
= Received Interference Power		-65.5	-65.5	-78.6	dBW
- LEO SAT-1 Transmit BW		86.0	80.0	89.0	dB-Hz
+ LEO B Transmit BW / Carrier		64.0	64.0	64.0	dB-Hz
= In-Band Interference Power		-87.5	-81.5	-103.6	dBW
C / N at LEO B Earth Station	38.0				dB
C / I at LEO B Earth Station		**-12.9**	**-18.9**	**3.2**	dB
C / I Required (Protection Ratio)	18.2				dB

Table 3.1 Interference Link Budget for Case 1: Interference from NGSO Satellite into the MSS Feeder Link Earth Station of the NGSO-MEO System

An example interference link budget is given in Table 3.1. In this example, a single NGSO earth station (standard terminal, mobile terminal or a high rate terminal) collocated with the MSS Feeder Link of the NGSO-MEO system is considered. The interference power is computed from a single NGSO satellite-to-earth station link when the satellites are "in-line" at 90° elevation from the point of view of the MSS feeder link earth station of the NGSO-MEO system.

Case 2: Interference from NGSO Earth Station into the MSS Feeder Link Satellite of the NGSO-MEO System

This case is shown in figure 3.4. The simulation procedure for this case is the same as that of case one with the exception that this case deals with the interference into the MSS Feeder Link satellite of the NGSO-MEO system. The location of the closest MSS Feeder Link satellite of the NGSO-MEO system is determined and then the sum of the interference from all the NGSO Earth Stations is calculated. It is assumed that the Uplink of the MSS feeder link NGSO-MEO system employs power control so that C/N at the satellite receiver is maintained at 31.3 dB.

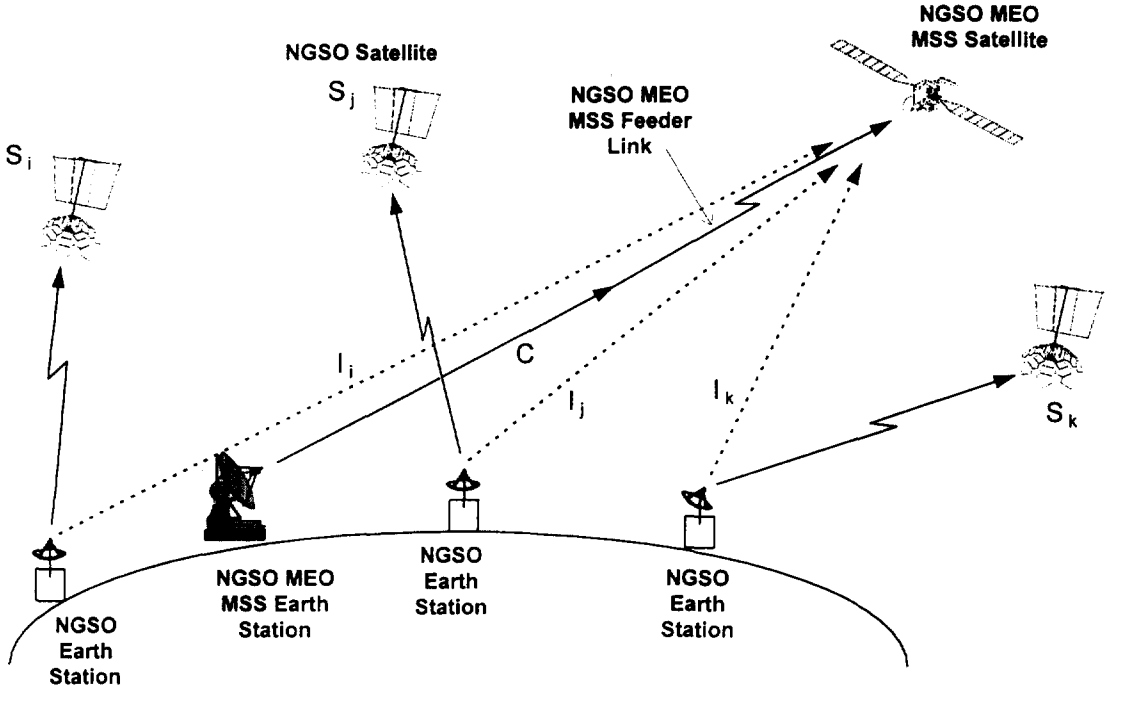

Figure 3.4 Case 2: Interference from NGSO Earth Station into NGSO-MSS Feeder-Link Satellite

An example interference link budget is given in Table 3.2. In this example, a single NGSO earth station (standard terminal, mobile terminal or a high rate

terminal) collocated with the MSS feeder link earth station of the NGSO-MEO system is considered. The interference power is computed from the single ground-to-satellite link when the satellites are "in-line" at 90° elevation from the point of view of the MSS feeder link earth station of the NGSO-MEO system.

Parameter	Desired	NGSO Interference			Units
	MSS Feeder Link of NGSO-MEO	Standard Link (T1)	Mobile Link (T1)	OC24 High Rate Link	
+ Transmit Power	-2.3 / Carrier	-3.6	2.4	-3.8	dBW
+ Transmit Antenna Peak Gain	64.8	36.0	30.0	50.0	dB
= Transmitted EIRP	62.5	32.4	32.4	46.2	dBW
- Transmission Loss	202.0	202.0	202.0	202.0	dB
+ Receiving Antenna Peak Gain	38.8	38.8	38.8	38.8	dB
= Received Carrier Power	-100.7				dBW
= Received Interference Power		-130.8	-130.8	-117.0	dBW
- LEO SAT-1 Transmit BW		74.2	74.2	89.0	dB-Hz
+ LEO B Transmit BW / Carrier		64.0	64.0	64.0	dB-Hz
= In-Band Interference Power		-141.0	-141.0	-142.0	dBW
C / N at LEO B Satellite	31.3				dB
C / I at LEO B Satellite		**40.3**	**40.3**	**41.3**	dB
C / I Req. (Protection Ratio)	18.2				dB

Table 3.2 Interference Link Budget for Case 2: Interference from NGSO Satellite Earth Station into a MSS Feeder Link Satellite of the NGSO-MEO System

Case 3: Interference from a MSS Feeder-Link Earth Station of the NGSO-MEO System into NGSO Satellite

This case is shown in figure 3.5. In this case the location of the NGSO satellite communicating with each earth station is calculated. The location of the MSS Feeder Link satellite of the NGSO-MEO system is also obtained. The transmitted power of the MSS Feeder Link Earth Station of the NGSO-MEO system is calculated such that the C/N at the MSS Feeder Link satellite of the NGSO-MEO system is constant. Then based on the location of the satellites the C/I at each NGSO satellite is calculated.

An example interference link budget is given in Table 3.3. In this example, the interference source, the MSS feeder link earth station of the NGSO-MEO system, is considered collocated with the desired link NGSO earth station (standard terminal, mobile terminal or high rate terminal). The satellites of both systems are "in-line" at 90° elevation from the point of view of the NGSO earth station.

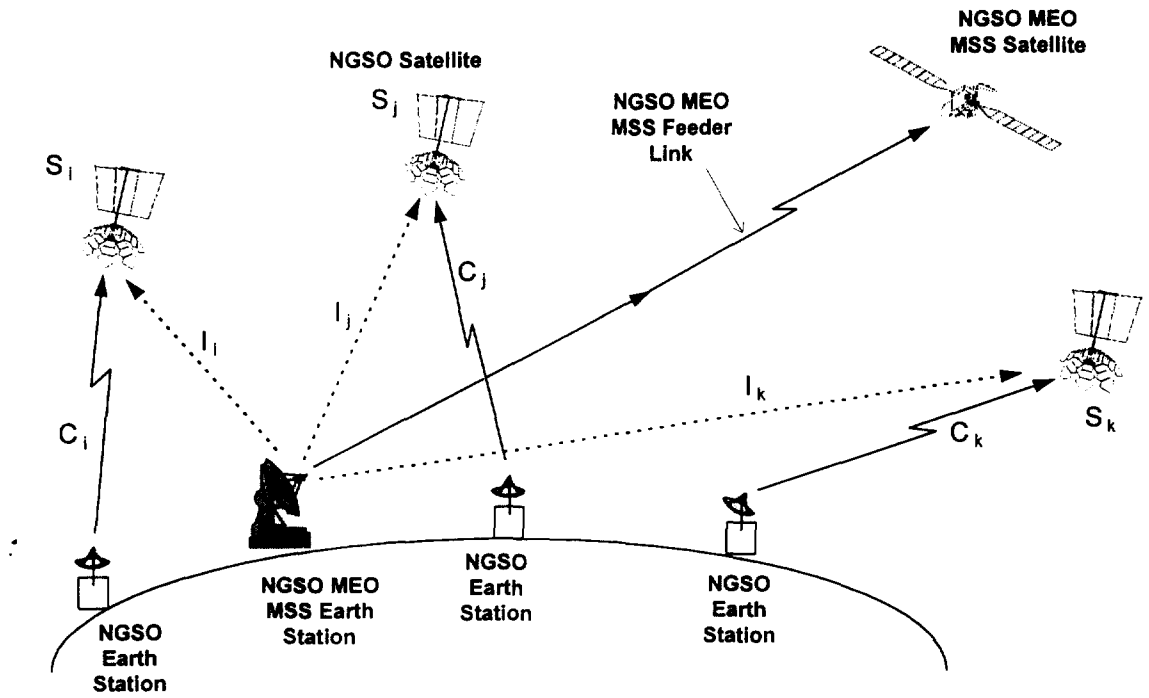

Figure 3.5 Case 3: Interference from MSS Feeder-Link Earth Station of the NGSO-MEO system into NGSO Satellite

Parameter	Desired			Interference	Units
	Standard Link (16K)	Mobile Link (16K)	OC24 High Rate Link	MSS Feeder Link of NGSO-MEO	
+ Transmit Power	-20.3	-14.3	-3.8	-2.3 / Carrier	dBW
+ Transmit Antenna Peak Gain	36.0	30.0	50.0	64.8	dB
= Transmitted EIRP	15.7	15.7	46.2	62.5	dBW
- Transmission Loss	178.5	178.5	178.5	178.5	dB
+ Receiving Antenna Peak Gain	29.8	29.8	41.0		dB
= Received Carrier Power	-133.0	-133.0	-91.3		dBW
Received Interference Power	-86.2	-86.2	-75.0		dBW
- LEO B Transmit BW	64.0	64.0	64.0		dB-Hz
+ LEO SAT-1 Transmit BW	54.4	54.4	89.0		dB-Hz
= In-Band Interference Power	-95.8	-95.8	-75.0		dBW
C / N at LEO SAT-1 Satellite	7.6	7.6	14.8		dB
C / I at LEO SAT-1 Satellite	**-37.2**	**-37.2**	**-16.3**		dB
C / I Req. (Protection Ratio)	25.0	25.0	25.0		dB

Table 3-3 Interference Link Budget For Case 3: Interference from MSS Feeder Link Earth Station of the NGSO-MEO System into NGSO Satellite.

Case 4: Interference from MSS Feeder-Link Satellite of the NGSO-MEO System into NGSO Earth Station

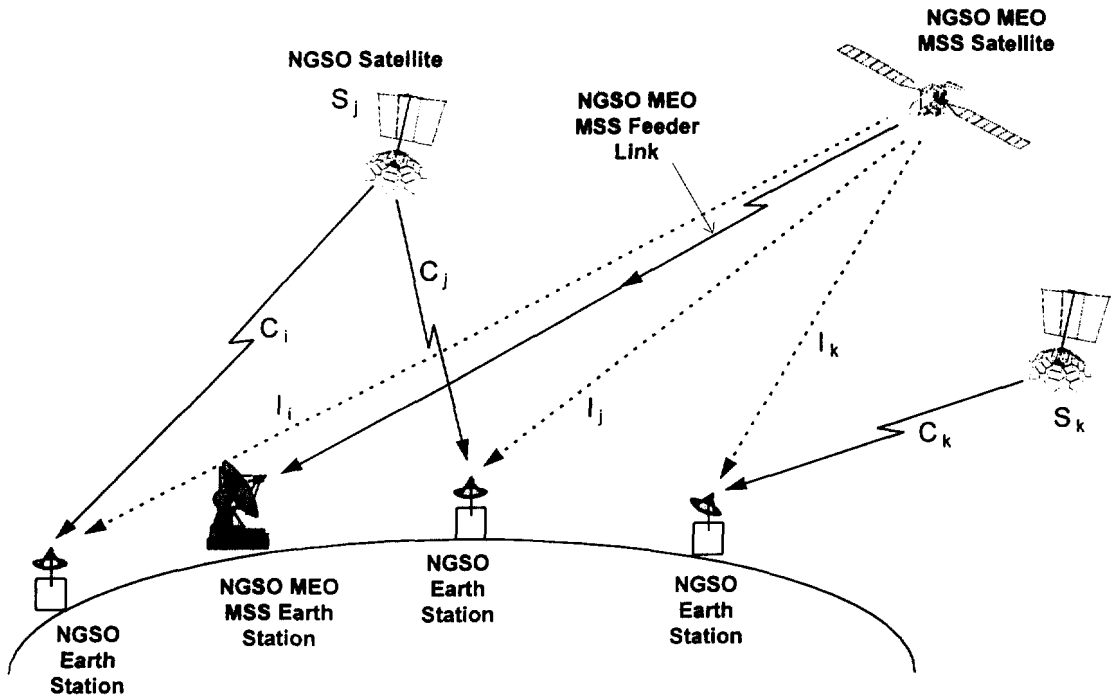

Figure 3.6 Case 4: Interference from MSS Feeder-Link Satellite of the NGSO-MEO system into NGSO Earth Station

Parameter	Desired			Interference	Units
	Standard Link	Mobile Link	High Rate Link	(LEO B) Earth Station	
+ Transmit Power	18.8	18.8	-5.5	1.3 / Carrier	dBW
+ Transmit Antenna Peak Gain	29.8	29.8	41.0	35.6	dBi
= Transmitted EIRP	48.6	48.6	35.5	36.9	dBW
- Transmission Loss	174.9	174.9	174.9	198.3	dB
+ Receiving Antenna Peak Gain	33.0	27.0	47.0		dB
= Received Carrier Power	-93.3	-99.3	-92.4		dBW
Rcvd Int. Power per Carrier	-128.4	-134.4	-114.4		dBW
Total # of Carriers (108)				20.3	dB
Total Rcvd Interference Power	-108.1	-114.1	-94.1		dBW
- LEO B Transmit BW	84.8	84.8	84.8		dB-Hz
+ LEO SAT-1 Transmit BW	86.0	80.0	89.0		dB-Hz
= In-Band Interference Power	-108.1	-118.9	-94.1		dBW
C/ I at LEO SAT-1 Terminal	**14.8**	**19.6**	**1.7**		dB
C / I Req. (Protection Ratio)	25.0	25.0	25.0		dB

Table 3.4 Interference Link Budget For Case 4: Interference from MSS Feeder Link Satellite of the NGSO-MEO System into NGSO Satellite Earth Station.

This case is shown in figure 3.6. In this case the location of the NGSO satellite communicating with each earth station is calculated. The location of the MSS Feeder Link satellite of the NGSO-MEO system is also obtained. The transmit power from the NGSO-MEO satellite toward its MSS Feeder Link earth station is maintained constant such that the interference power at the NGSO earth station is a function of antenna off-axis angle and propogation distance.

An example interference link budget is given in Table 3.4. In this example, the interferer, NGSO MSS satellite is considered transmitting to a feeder link earth station collocated with the NGSO earth station (standard terminal, mobile terminal and high rate terminal) of the desired link. The satellites of both systems are "in-line" at 90° elevation from the point of view of the NGSO earth station.

4.0 Simulation Results

4.1 Simulation Results with C/I as the Performance Criteria

The simulation program described in the previous section is used to calculate the interference statistics between the MSS feeder links of a NGSO-MEO system, and the FSS and MSS service and feeder links of another NGSO satellite system. The simulation statistical results discussed in this paper are based on a simulation period of one week in order to average out any short-term fluctuations. The output of the simulation program is the time history of the C/I at each simulation step. In order to gain additional insight and understanding of the simulation results, a post processor program is developed that calculates and plots the following statistics:

a) C/I time history
b) C/I probability density function and cumulative probability distribution function
c) Interference event duration statistics
d) Interval between interference events statistics

The interference between the MSS feeder links of the NGSO-MEO system and three different NGSO satellite system links are considered

1) The MSS Feeder Links of the NGSO-MEO system and the NGSO satellite system standard earth station links (FSS and MSS services and Feeder Links)

The results of the simulation for case 1 are shown in figures 4.1 through 4.4. Figure 4.1 shows the time history of C/I and figure 4.2 shows that the probability of interference in the case when the NGSO standard earth station is collocated with the NGSO-MEO MSS feeder link earth station is equal to 0.05%. Figure 4.3

shows the time history of C/I and figure 4.4 shows that the probability of interference will drop below 0.01 if there is a 160 km separation between the NGSO standard earth station and the MSS feeder link ground station of the NGSO-MEO system. There were not enough interference events to illustrate the statistics of the duration of an interference event or the statistics of the time between interference events. However the numerical results of the first order statistics are given in table 4.1.

The results of the simulation for case 2 are shown in figures 4.5 through 4.8. No interference events were found even if the NGSO standard terminal is collocated with the MSS feeder link ground station of the NGSO-MEO system.

The results of the simulation for case 3 are shown in figures 4.9 through 4.14. Figure 4.9 shows the time history of C/I and figure 4.10 shows that, for the case when the NGSO standard earth station is collocated with the NGSO-MEO MSS feeder link earth station, the probability of interference is equal to 16.2%. Figures 4.11 and 4.12 show the statistics of the interference event duration and the statistics of the duration between interference events respectively.

Figures 4.13 and 4.14 shows the results when there is a 160 km separation between the NGSO standard earth station and the MSS feeder link ground station of the NGSO-MEO system. In this case the probability of interference reduces to 0.07%. This is because the LEO SAT-1 satellite receiving antenna will provide an additional discrimination of 35 dB in the direction of the MSS feeder link ground station of the NGSO-MEO system.

The results of the simulation for case 4 are shown in figures 4.15 through 4.22. Note that there is not much improvement in the probability of interference when the collocated NGSO standard terminal is removed in this case. The probability of interference drops from 0.5% (Figure 4.16) to 0.38% (Figure 4.20). This is due to the fact that the altitude of the NGSO-MEO satellite is much higher than that of the NGSO-LEO satellite and because the main beam of the NGSO-MEO satellite covers a very large area on the earth surface, the interference into the non-collocated earth stations would be almost the same as that into the collocated earth station.

2) The MSS Feeder Links of the NGSO-MEO system and the NGSO satellite system mobile earth station links (FSS and MSS services and Feeder Links)

The statistics of interference for case 1 are shown in figures 4.23 through 4.26. and the statistics for case 4 are shown in figures 4.27 through 4.30.

The interference event in case 1 occurs more often than the case with standard earth station links. For example when one mobile station is collocated with the MSS feeder link ground station of the NGSO-MEO system, the probability of interference event is 0.13% (Figure 4.24) compared with 0.05% for the standard link case (Figure 4.2).

The interference event in case 4 occurs less often than the case with standard earth station links For example when one mobile station is collocated with the MSS feeder link ground station of the NGSO-MEO system, the probability of interference event is 0.19% (Figure 4.28) compared with 0.5% for the standard link case (Figure 4.16).

The interference statistics of the mobile earth station for case 2 and case 3 are similar to the statistics of the standard earth station and are not plotted.

3) The MSS Feeder Links of the NGSO-MEO system and the NGSO satellite system high rate earth station links (FSS and MSS services and Feeder Links)

The probability of interference between the MSS feeder link of the NGSO-MEO system and the NGSO high rate earth station links is rather small as seen in figures 4.31 through 4.42. It can be seen that the probability of interference event for case 1 is less than 0.01, for case 2, the interference is non-existent, for case 3, it is 0.23% and for case 4 it is 0.15%. The number of interference events for case 1 occurring during the simulation period is too small and reliable statistics can not be obtained from the data. The non-collocated cases were not even considered.

Table 4.1 summarizes the results of the simulation runs.

		NGSO Earth Station Collocated with the MSS Feeder Link Earth Station of the NGSO-MEO System				NGSO Earth Station at 160 km separation from the MSS Feeder Link Earth Station of the NGSO-MEO System			
		Probability of Interference (%)	Mean Interference event Duration (sec)	Maximum Interference Event Duration (sec)	Mean Time Between Events (min)	Probability of Interference (%)	Mean Interference event Duration (sec)	Maximum Interference Event Duration (sec)	Mean Time Between Events (min)
Standard Earth Station	Case 1	0.05	3.4	6.0	124.2	< 0.01	2.0*	2.0*	1573.2
	Case 2	0.0	0.0	0.0	N/A	0.0	0.0	0.0	N/A
	Case 3	16.2	51.6	116.0	4.5	0.07	19.4	25.0	109.2
	Case 4	0.5	9.7	16.0	38.2	0.38	9.2	16.0	39.2
Mobile Earth Station	Case 1	0.13	5.5	8.0	70.9	< 0.01	2.0*	2.0*	595.5
	Case 2	0.0	0.0	0.0	N/A	0.0	0.0	0.0	N/A
	Case 3	16.2	51.6	116.0	4.5	0.07	19.4	25.0	109.2
	Case 4	0.19	6.8	12.0	58.6	0.14	6.0	10.0	66.6
High Rate Earth Station	Case 1	< 0.01	2.0*	2.0*	N/A				
	Case 2	0.0	0.0	0.0	N/A				
	Case 3	0.23	7.2	12.0	51.9				
	Case 4	0.15	6.2	10.0	67.1				

Table 4.1

* The number of interference events occurring during the simulation period is too small to obtain any reliable statistics from the data.

4.2 Simulation Results with Io/No as the Performance Criteria

Another criteria that can be used to measure the severity of the interference between the two systems is based on the I_0/N_0.

Short term interference criteria is related to short term performance objectives and is specified in terms of the allowable excess noise level during an allowable percentage of time. The total interference level (I) is compared with the receiver thermal noise level (N_T). We are interested in calculating the " Probability of occurrence of a given level of interference specified as a fraction of the total, long term, link noise allowance ", i.e. Prob($I \geq k\ N_T$). Based on the performance objectives in Recommendation ITU-R S.1062, the following values were used as acceptable interference levels

I	% of time
Negligible	0.87
0.78 N_T	0.119
2.98 N_T	0.0294
14.8 N_T	0.0004

Note that the " Negligible " entry in the above table corresponds to the threshold on the maximum allowable total system noise temperature increase, i.e. $\Delta T/T$. LEO B specifies it's $\Delta T/T$ to be less than 6% (i.e. -12.2 dB), where as LEO SAT-1 specifies it's $\Delta T/T$ to be less than 2% (i.e. -17.0 dB) for it's standard and mobile links and 9% (i.e. -10.2 dB) for it's high data rate links.

The above table was derived by considering the interference events as equivalent to fading events. This is not necessarily true since the interference from NGSO MSS feeder links are usually short and strong and occur more often than fading events and hence another criteria is needed regarding the frequency of occurrence of the interference events. Interference levels exceeding 14.8 N_T must not occur more than once every 14 days during any period.

Note that the single entry time percentage values in the above table corresponds to the total (Aggregate) interference allowance received from all the satellites and earth stations in a single interfering network.

Table 4.2 summarizes the percentage of time that the permissible I/N_T is exceeded for each interference case between the NGSO-MEO MSS feeder links and the NGSO standard links at latitude 34°. The bold entries in tables 4.2 indicate that the ITU recommendated percentage of occurrence is not met in these cases.

Interference Level (Fraction of N_T)	Maximum Allowed % Time	Case 1 NGSO-MEO ES	Case 2 NGSO-MEO satellite	Case 3 NGSO satellite	Case 4 NGSO E/S
Negligible	0.87	**12.1**	0.0	**15.1**	**11.3**
$I = 0.78\ N_T$	0.119	**1.6**	0.0	**0.82**	**0.4**
$I = 2.98\ N_T$	0.0294	**0.5**	0.0	**0.28**	**0.13**
$I = 14.8\ N_T$	0.0004	**0.14**	0.0	**0.07**	0.0

Table 4.2: Percent Time Interference Level Exceeds Threshold for NGSO Standard Links at 34° N Latitude.

Table 4.3 summarizes the percentage of time that the permissible I/N_T is exceeded for each interference case between the NGSO-MEO MSS feeder links and the NGSO mobile links at latitude 34°. The bold entries indicate that the ITU recommendated percentage of occurrence is not met in these cases.

Interference Level (Fraction of N_T)	Maximum Allowed % Time	Case 1 NGSO-MEO ES	Case 2 NGSO-MEO satellite	Case 3 NGSO satellite	Case 4 NGSO E/S
Negligible	0.87	**46.6**	0.0	**15.1**	**4.95**
$I = 0.78\ N_T$	0.119	**4.8**	0.0	**0.82**	**0.18**
$I = 2.98\ N_T$	0.0294	**1.6**	0.0	**0.28**	0.0
$I = 14.8\ N_T$	0.0004	**0.44**	0.0	**0.07**	0.0

Table 4.3: Percent Time Interference Level Exceeds Threshold for NGSO Mobile Links at 34° N Latitude.

Table 4.4 summarizes the percentage of time that the permissible I/N_T is exceeded for each interference case between the NGSO-MEO MSS feeder links and the NGSO high rate links at latitude 34°. The bold entries indicate that the ITU recommendated percentage of occurrence is not met in these cases.

Interference Level (Fraction of N_T)	Maximum Allowed % Time	Case 1 NGSO-MEO ES	Case 2 NGSO-MEO satellite	Case 3 NGSO satellite	Case 4 NGSO E/S
Negligible	0.87	0.21	< 0.01	0.23	0.34
$I = 0.78\ N_T$	0.119	0.03	0.0	0.045	0.06
$I = 2.98\ N_T$	0.0294	0.01	0.0	0.015	0.026
$I = 14.8\ N_T$	0.0004	< 0.01	0.0	< 0.01	< 0.01

Table 4.4: Percent Time Interference Level Exceeds Threshold for NGSO High Rate Links at 34° N Latitude.

5. Conclusion

This paper presents statistical results that are useful in evaluating the potential for frequency sharing. However, the exact criteria for frequency sharing between the MSS feeder links of NGSO-MEO system, and the FSS and MSS, Service and Feeder links of another NGSO Satellite System have not been defined.

The simulation results indicate a positive potential for sharing between the MSS Feeder Links of the NGSO-MEO system and the NGSO Satellite System High Rate Links (FSS Service Links and MSS Feeder Links). Additional work is required to determine the minimum separation requirement based on the acceptable interference levels.

The interference levels between the MSS Feeder Links of the NGSO-MEO system and the NGSO Satellite Systems Standard and Mobile Links are higher. Earth station site separation reduces the interference problem but does not eliminate it. Additional work is required to determine the effect of other mitigation techniques in improving the sharing potential.

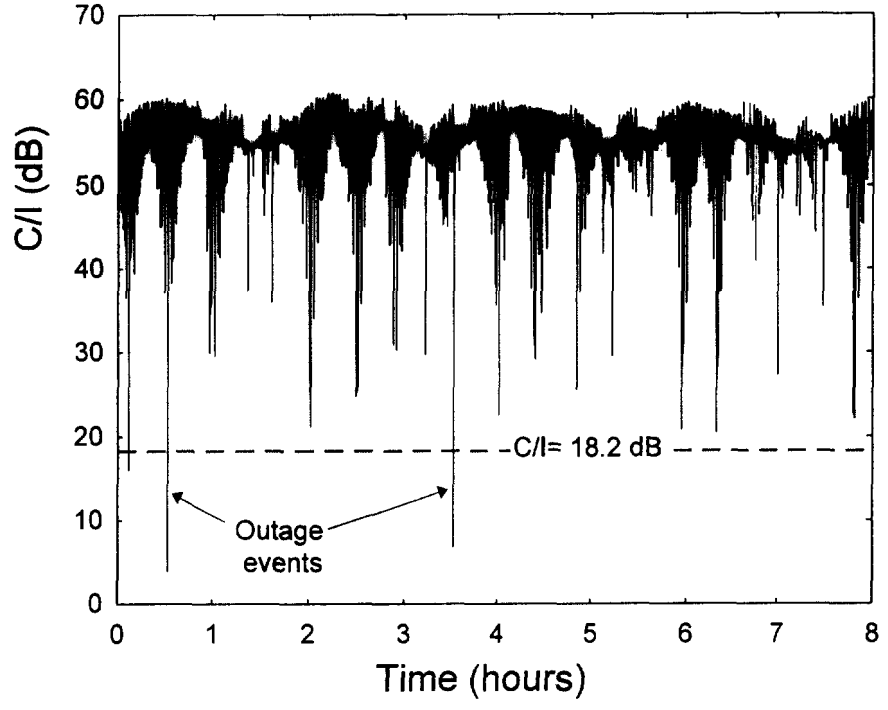

Figure 4.1 CASE 1, C/I Time History, Collocated Standard Earth Station.

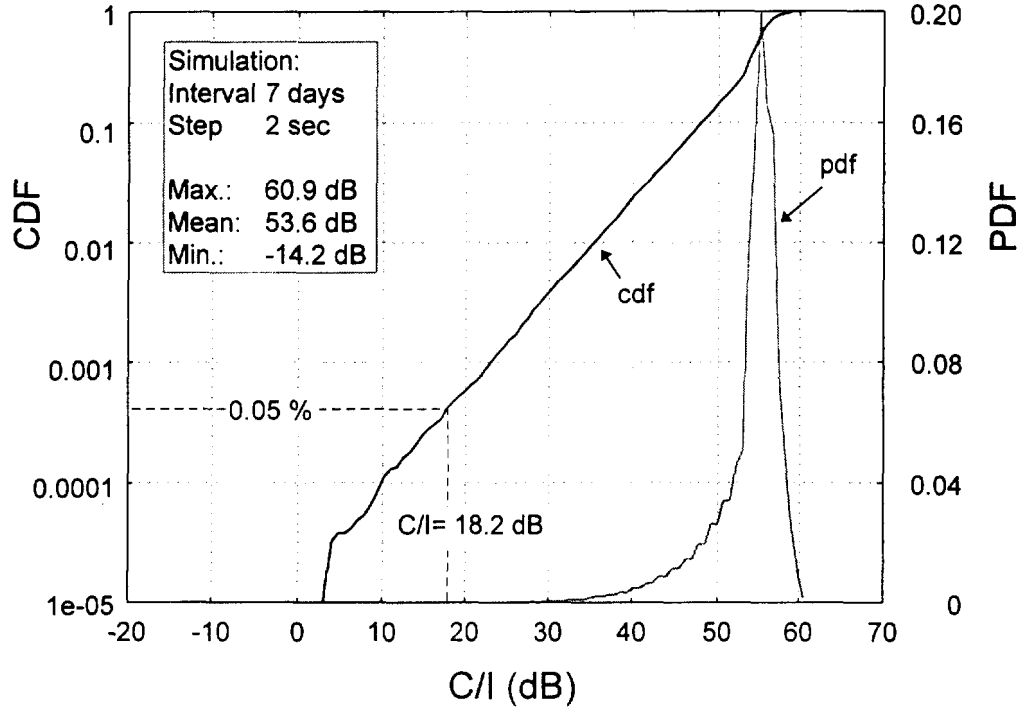

Figure 4.2 CASE 1, C/I Probability, Collocated Standard Earth Station.